CENTRALIZED TRAFFIC CONTROL AS A MEANS OF ACCELERATING TRAIN MOVEMENTS

BY

WAI-YUM YEE

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M.S., Massachussetts Institute of Technology, 1941

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CENTRALIZED TRAFFIC CONTROL AS A MEANS OF ACCELERATING TRAIN MOVEMENTS

Introduction

Centralized Traffic Control has been widely recognized as one of the most effective means of accelerating train movements as well as improving traffic capacity under given conditions of track, motive power, and tonnage capacity, to permit maximum speed. Justification of its economic value on any railroad has to be found in the comparison of its cost and the possible saving of road time or increase of traffic capacity which requires an attempt to evaluate the expected results before the installation of the system. It is possible to visualize very roughly the expected effect of Centralized Traffic Control on any railroad by studying the results of existing installations on other railroads. However, such a judgment is unreliable because of the difference in the various characteristics on different railroads. What is justified on one railroad is not necessarily justified on the other. A more accurate method generally used for making such predictions on Centralized Traffic Control consists of graphically redispatching the trains in order to foresee their probable operations under the new system.

The purpose and scope of this thesis is to develop mathematical solutions to replace or at least, to corroborate the graphical redispatching method in predicting the effect of substituting Centralized Traffic Control for the train-order, time-table and manual block signaling system of operation on single track roads under various traffic conditions. The mathematical solutions developed are much simpler than the graphical method and have been proved to be applicable by the comparison of the mathematically computed results with the reported actual results from eight installations on seven different railroads. It is not expected that the method suggested in this thesis will give definite and precise predictions on the effect of Centralized Traffic Control; but it will give results that are reasonably close to what may be expected from the system.

SUMMARY

The Signal Section, Association of American Railroads, defines Centralized Traffic Control as:

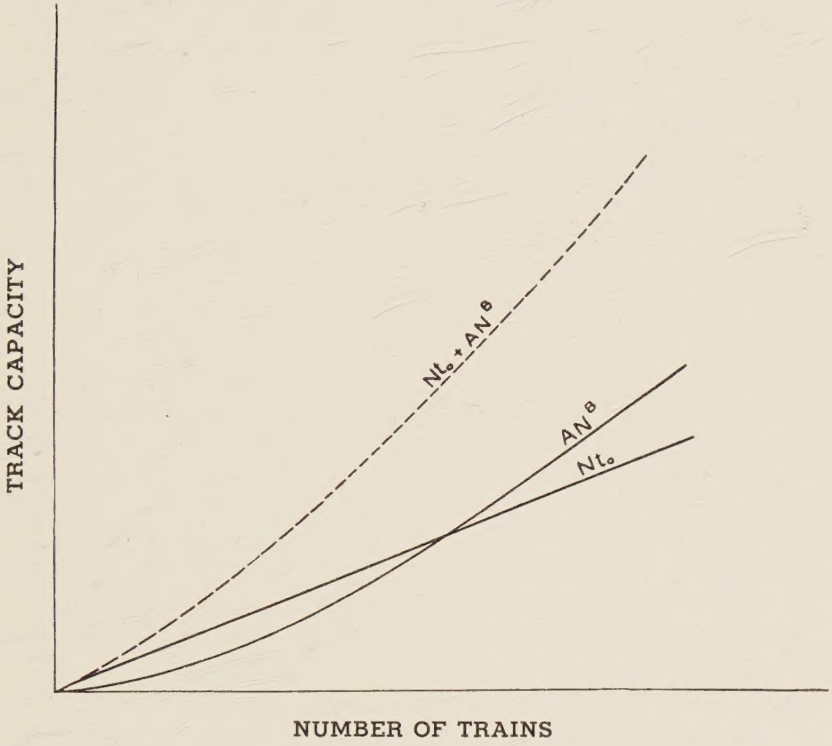
"A term applied to a system of railroad operations by means of which the movement of trains over routes and through blocks on a designated section of track or tracks is directed by signals controlled from a designated point without requiring the use of train orders and without the superiority of trains."

Because of the concentration of operation and the elimination of train orders, Centralized Traffic Control tends to reduce the road time of the trains operated on any section. The road time of a train consists of its running time and its delay time. If there is no change in the speed of the trains before and after the installation of Centralized Traffic Control the running time would remain constant under any system of operation, and the function of Centralized Traffic Control is, therefore, to minimize the delay time of the trains. Train delays are mainly of two types—those occurring in train meets and passings and those occurring because of accidents of operation. The number of train meets and passings is a function of the number of trains on the road. It follows that train delays also vary with the number of trains; that is, the more trains put out on the road the greater is the delay time.

If the term "track capacity" is used to denote the product of the average road time of the trains and the number of trains that can be handled between any two points of any section of road between terminals, then with the same number of trains on the road, Centralized Traffic Control would decrease the track capacity of that section, or in other words, it would reduce the average road time of the trains. Similarly, with the same track capacity Centralized Traffic Control would increase the number of trains that can be put out on that section for a designated length of time. Track capacity is measured in train-hours per day or train-minutes per day.

If the track capacity per day of any section of road under actual operation is plotted against the corresponding number

of trains per day, a curve obtained in this manner would have a shape such as that shown in the figure.



The equation for the curve should consist of two parts—one showing the number of train-hours of running time and the other showing the number of train-hours of delay. The shape of the curve also suggests an exponential equation. Hence, the equation may be expressed in the following form,

$$C = Nt_o + AN^B$$

where

C = track capacity in train-hours (or train-minutes) per day
N = number of trains per day
t_o = running time of the trains in hours (or minutes)
A and B are delay coefficients

Using data, furnished to the writer by the Union Switch and Signal Company, for the Pere Marquette Railroad between Bridgeport and Mt. Morris, Michigan, comprising records of two years of observation on the number of trains per day and the corresponding track capacity under the operation of the train-order, time-table and manual block signaling system and one year of observation under Centralized Traffic Control, the equations representing the relationship between the number of trains and the corresponding track capacity on the Pere Marquette section are established as,

$$C_b = 35N_b + 0.29877N_b^{2.57065}$$
$$C_a = 35N_a + 0.14751N_a^{2.57281}$$

where C_a and C_b are expressed in train-minutes.
In the above two equations and in all the equations which follow the subscripts "b" and "a" are used to indicate, respectively, operations under the train-order, time-table and manual block signaling system and under Centralized Traffic Control.

It is found that meet-delay is a function of the square of the corresponding number of trains. Including the delays due to accidents which, according to the law of probability, increase when the number of trains increases, the total delay which includes meet-delay and accident-delay must be increased at some higher rate than that indicated by the square of the number of trains. This may be indicated by the values of the delay coefficient B in the two equations. Under normal operation it may be assumed that there is a mathematical relationship between accident delays and the number of trains. The closeness of the values of the two exponents, 2.57065 and 2.57281, which were determined from the data taken on three separate years and under two different systems of operation suggests the confirmation of the assumption. If this assumption is accepted the delay coefficient B can be treated as a constant. Then the formulae representing the relationship of the track capacity and the number of trains on the Pere Marquette section may be written as,

$$C_b = 35\,N_b + 0.29877\,N_b^{2.57}$$
$$C_a = 35\,N_a + 0.14751\,N_a^{2.57}$$

Taking into account the various factors, such as the length of the division, the number of passenger trains, the speed of the trains and the number of trains from one direction, the general formulae which may be applicable to any single track divison under any traffic condition, if there is no change in the track arrangements after the installation of Centralized Traffic Control, are developed as,

$$C_b = \frac{60\,M\,N_b}{V_b} + 0.0714\,M\,j_b\,N_b^{2.57}$$

$$C_a = \frac{60\,M\,N_a}{V_a} + 0.0351\,M\,j_a\,N_a^{2.57}$$

$$j_b = \frac{p_b\,(1 - p_b)}{F_b}$$

$$j_a = \frac{p_a\,(1 - p_a)}{F_a}$$

$$F_b = \left(\frac{N_{Fb} + N_{Pb}}{N_{Fb} + 0.6\,N_{Pb}}\right)^{2.57}$$

$$F_a = \left(\frac{N_{Fa} + N_{Pa}}{N_{Fa} + 0.6\,N_{Pa}}\right)^{2.57}$$

where

M = length of division in miles
V = average running speed of trains in miles per hour
N_F = number of through freight trains per day
N_P = number of passenger trains per day
p = ratio of the number of trains from one direction to the total number of trains

When there is an increase of the mileage of passing sidings after the installation of Centralized Traffic Control the track capacity formula for operation under Centralized Traffic Control becomes,

$$C_a\left(\frac{M_s + M_{as} + L}{M_s + L}\right) = \frac{60\,M\,N_a}{V_a} + 0.0351\,M\,j_a\,N_a^{2.57}$$

where

M_s = length of existing sidings in miles
M_{as} = length of added passing sidings in miles
L = average length of trains in miles

The formulae for determining the average road time of the trains before and after the installation of Centralized Traffic Control are found as,

$$T_{mb} = \frac{60\,M}{V_b} + 0.0714\,M\,j_b\,N_b^{1.57}$$

$$T_{ma} = \frac{60\,M}{V_a} + 0.0351\,M\,j_a\,N_a^{1.57}$$

where

T_m = average road time of the trains in minutes

All the formulae have been derived under the assumption that the train-order, time-table and manual block signaling system has been utilized to its full extent and they are correctly applicable only under such condition. If the system has not been efficiently operated the actual results in the saving of road time or in the increase of the number of trains after the installation of Centralized Traffic Control may be expected to be higher than that indicated by the formulae.

Using the formulae to investigate the effect of Centralized Traffic Control on single track lines when used to substitute for the train-order, time-table and manual block signaling system to reduce the average road time of the trains, the following conclusions are reached:

1. No specific saving in time or percentage can be stated as resulting from the introduction of Centralized Traffic Control. This saving is determined by the following factors—the number of trains operated, the running speed of the trains, the number of passenger trains and the ratio of the number of trains from one direction to the total number of trains.
2. For any definite running speed, the saving in road time increases when the number of trains increases.

3. For any definite number of trains, the saving in road time increases when the running speed of the trains increases.
4. When the number of trains operated is below 30 the saving in road time increases uniformly with the increase of the running speed of the trains.
5. When the number of trains operated is above 30 there is an extreme saving in road time if the trains are operated below 30 miles per hour; any further increase in the running speed beyond this limit does not increase the saving very effectively.
6. For any number of trains operated at any speed, the saving in road time increases as the number of passenger trains decreases.
7. For any number of trains operated at any speed, the less the difference in the number of trains from the two directions the greater is the percentage of saving in road time.

The mathematical investigation also shows that under ordinary traffic conditions where the number of freight trains is about 50% of the total number of trains and the number of trains from both directions is the same, the saving of road time per train mile due to Centralized Traffic Control ranges from 0.190 minutes for 10 trains per day to 4.040 minutes for 70 trains per day. Between 30 trains per day and 40 trains per day, which may represent the ordinary traffic density for single track roads, the saving in road time ranges from 1.069 minutes per train mile to 1.678 minutes per train mile. These results agree with the statistical study of 19 Centralized Traffic Control installations on 17 different railroads made by the Signal Section of the Association of American Railroads. The statistical study showed that the average train time saved per installation amounted to 1.38 minutes per train mile, and the minutes saved per train mile varied from 0.27 to 4.29 on the 19 installations; for ordinary traffic conditions on single track line, a reduction of 1 minute to 1.5 minutes per train mile was expected.

Basing on the same statistical study, the Signal Section also stated that if the saving up to 40 trains per day was plotted on a trend curve the curve showed that the percentage of train time saved varied nearly as the number of trains; that is, 20% time saving for 20 trains, 30% time saving for 30 trains and 40% time saving for 40 trains; and that below 30 trains per day the trend curve ran higher than the number of trains. For ordinary traffic conditions the computed results show a close agreement with the statement.

For checking the accuracy of the formulae when applied to individual cases, eight reports showing the percent of saving of road time after the installation of Centralized Traffic Control from seven different railroads are chosen at random to compare with results computed with the formulae. All these installations are on single track lines and train-order, time-table and manual block signaling systems were used to direct train operation before the installation of Centralized Traffic Control. The statistical average percent of road time saving of the eight installations is 31.4 while the computed result is 28.6 percent. The statistical percentage and the computed percentage of road time saving on each individual case agree reasonably, having a difference of about two to six percent in different cases.

Using Centralized Traffic Control as a means of increasing traffic capacity which is defined as the number of trains that can be put out in one day on any section of the road between terminals, the computations with the formulae show the following conclusions:

1. The percentage of increased traffic capacity after the installation of Centralized Control is not definite; it varies with the traffic capacity before the installation, the running speed of the trains, the number of passenger trains and the ratio of the number of trains from one direction to the total number of trains.
2. An increase of traffic capacity is accompanied by a decrease in the road time of the trains. When there is no change in the mileage of the sidings after the in-

stallation, the percent of road time reduced for any corresponding increase in traffic capacity equals the increased number of trains times 100 and divided by the total number of trains operated under Centralized Traffic Control. The higher the percentage of increased traffic capacity the higher is the percentage of the corresponding reduced road time.

3. Any increase in the mileage of the passing sidings after the installation further increases the traffic capacity.
4. The greater the number of trains operated before the installation the higher are the percentages of the increased traffic capacity and of the corresponding reduced road time after the installation.
5. The higher the running speed of the trains the higher are the percentages of the increased traffic capacity and of the corresponding reduced road time.
6. The greater the percentage of passenger trains on the road, the lower are the percentages of the increased traffic capacity and of the corresponding reduced road time.

If there is no change in the mileage of the passing sidings after the installation of Centralized Traffic Control, under ordinary traffic conditions where the number of trains is about 30 per day and the trains are operated at about 30 miles per hour, the installation may result in an increase in traffice capacity of 20% to 25% and a corresponding decrease in road time of 17% to 20% depending upon the number of passenger trains on the road, and 30% is about the maximum increase in traffic capacity. With a reasonable increase of the mileage of the passing sidings after the installation of Centralized Traffic Control the increase of traffic capacity may be expected to be from 25% to 45% or higher depending upon the length of the added sidings and the traffic conditions.

If the number of trains and the average road time of the trains are desired to be kept the same after the installation of Centralized Traffic Control, it is possible to run the trains at a much lower speed. In such cases the tonnage capacity of the trains may be greatly increased. The amount of tonnage that can be increased depends upon the type of motive power

used and the character of the road. For ordinary cases, according to mathematical computations it is posible to increase the tonnage capacity of the trains by 80% or 90% without any loss in traffic capacity nor any increase in the road time. In some installations 85% increase of tonnage capacity has been reported.

Because of the numerous variables involved the most effective use of Centralized Traffic Control on any particular road has to be determined by a detailed economic study considering all the elements that are characteristic of the road. Every local condition subjected to study presents its own problem. In general, installation of Centralized Traffic Control on single track lines where traffic capacity is 20 or more trains a day, is, undoubtedly, economically justified as has been proven on many existing installations.

VITA

Wai-Yum Yee was born in Toyshan, Kwangtung, China, May 27, 1917. After his graduation from Wah Yan College in Hongkong, he entered Lingnan University in Canton and received the degree of Bachelor of Science in Civil Engineering in June, 1940. He graduated with honors in that University and became a member of Phi Tau Phi, the national honorary fraternity of China. He continued his study in Massachusetts Institute of Technology and was granted the degree of Master of Science in Civil Engineering in June, 1941. Following that he attended Columbia University for one semester. Since that time he has been continuing his graduate work at the University of Illinois. In the summer of 1942 he worked for the Union Switch and Signal Campany, Swissvale, Pennsylvania, gathering data for his thesis.